Special Report Series, No. 49.

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On the Destruction of Bacteria in Milk by Electricity.

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On the Destruction of Bacteria in Milk by Electricity

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INTRODUCTION

The Medical Research Committee believe that it may be useful to many at the present time to have easy access to the detailed account given here by Professor Beattie of an electrical method for sterilization of milk, of which an earlier description was published by the City of Liverpool in 1915. At the beginning of their work in 1914, the Committee arranged to give some assistance to these studies at Liverpool, and at the same time they were able to secure an independent trial of the method in another centre of population—at Birmingham—where Professor Leith undertook to repeat and extend the Liverpool observations, with the aid of an assistant whose services were provided by the Committee. Sir Oliver Lodge was good enough to superintend the study of current action upon its technical side, and Professor Beattie kindly put at Professor Leith's disposal some of his own apparatus for use.

Professor Leith used in his experiments the natural milk of tuberculous cows, and he made a large number of observations in the earlier part of the war upon the effect both of the electrical current and of heat alone as sterilizing agents. Unfortunately, the war brought many interruptions and difficulties to the inquiry, and Professor Leith gave up his University work at Birmingham before it could be resumed. Nevertheless, the results which he had already obtained and reported to the Committee confirmed Professor Beattie's claim for the efficiency of the electrical method in sterilizing infected milk. The Birmingham workers found a close parallelism between the effects of heat and of the electrical current respectively upon the organisms in the milk, and they concluded that the electrical method owes its results not to the direct action of the current as such upon the bacilli, but to the heat generated in its passage; to them both methods alike were thermal methods of destruction. They were led to believe that in the electrical method the current raises the temperature of the milk more quickly, and since it passes through every part of the milk, the heat which it generates reaches every part of the milk at the same moment. It has this advantage over the simpler thermal method. Further, though the heat is generated always at the same rate, it increases with the length of the milk column traversed by the electrical current, and hence, as in the thermal method, the temperature of the milk will continue to increase until it reaches its highest point as it issues from the tube. The heat

conditions of the two methods are, therefore, very similar. Their sterilizing power is also similar, though the electrical is quicker in its action, and Professor Leith summarized his report by saying that ' both the thermal and electrical methods have a high practical value, and deserve consideration in any endeavour made to improve milk supplies. The thermal is simpler and cheaper, the electrical quicker in action '.

Professor Leith suggested further that both methods could be made more efficient by grafting on them the practice of pasteurizing by two treatment applications, with rapid cooling of the milk after each, and that even with a single application the milk would store better if rapidly cooled after treatment.

In the opinion of the Committee the experiments at Birmingham, though they entirely support the practical results obtained by Professor Beattie and Mr. Lewis at Liverpool, were not complete enough on their bacteriological side to settle finally the question whether the electrical current in this method has a direct bactericidal action or whether it acts purely as a thermal agent. Sir Oliver Lodge was strongly of opinion that its action was purely thermal. It must be hoped that this question may presently be settled by special inquiry : in the meantime there is no doubt that the work of Beattie and Lewis has given us an elegant and practical method of purifying milk for human consumption, of which the use upon a large scale becomes now a problem for closer financial and administrative examination.

Medical Research Committee,
15 Buckingham Street,
Strand, W.C. 2.

February 20, 1920.

ON THE DESTRUCTION OF BACTERIA IN MILK BY ELECTRICITY

BY

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AND

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IN the proceedings of the Pathological Society of Great Britain and Ireland, published in the *Journal of Pathology and Bacteriology*, vol. xviii, 1913–14, we communicated a preliminary note of the 'Utilisation of Electricity in the sterilisation of milk'. A report on the work was submitted to the Health Committee of the City of Liverpool in June 1913, and a later and much fuller report giving details and photographs of the apparatus, &c., on April 16, 1914. This latter was published as a monograph by the city in 1915. Since the time of that report the work has been carried on with necessarily very many and serious interruptions up to the present time. During the progress of the work several papers have been published, but it is only now that the work has reached the stage when it is possible to review it, to publish full details, and to deal with the main objections which have been brought to our notice. This publication seems all the more desirable in view of the recent issue of the third Interim Report of the Committee on the Production and Distribution of Milk. Any one noting the bacterial analyses obtained in various laboratories and recorded in this report must agree that pasteurization as carried out commercially is not an efficient method of ridding milk of *B. coli* and other organisms. It is only when temperatures of about 180° F. are reached that anything like sterilization is obtained.

The results of examinations which have been made in our laboratory of commercial pasteurized milk are indicated in a typical example set out in the following table:

TABLE I.

Sample of	*Bacteria per c.c.*	B. coli *present in*
A. Untreated milk	3,840,000	0·0001 c.c.
Pasteurized milk (not cooled) . .	1,160,000	absent in 1 c.c.
,, ,, (cooled) . . .	240,000	0·1 c.c.
B. Untreated milk	1,080,000	0·0001 c.c.
Pasteurized milk (not cooled) . .	360,000	0·1 c.c.
,, ,, (cooled) . . .	520,000	0·1 c.c.

In other samples we have found *B. coli* present in 0·001 c.c. of pasteurized milk, but the common standard as shown by reports

from various laboratories is the presence of *B. coli* in 0·1 c.c., and this immediately after pasteurization. When one realizes the rapidity with which *B. coli* grows, the multiplication will be considerable before the milk is used by the general public. In examination of the duplicates of the samples recorded in the above table after three days—the bottles being sealed at the dairy and only opened on the third day—the following results were obtained :

TABLE II.

Sample of	*Bacteria per c.c.*	B. coli *present in*
A. Untreated milk (3 days) . . .	65,600,000	0·00001 c.c.
Pasteurized milk (not cooled), 3rd day	168,000,000	0·00001 c.c.
,, ,, (cooled) 3rd day .	240,000	0·1 c.c.
B. Untreated milk	uncountable	0·00001 c.c.
Pasteurized milk (not cooled), 3rd day	,,	0·00001 c.c.
,, ,, (cooled), 3rd day .	,,	0·00001 c.c.

Our work on this subject suggests that if bacteria are left in pasteurized milk (especially if not cooled rapidly), that their multiplication is more rapid than in untreated milk.

If we compare these results with those obtained with milk treated by the electrical process the contrast is marked. The following table (Table III) gives the results obtained in consecutive examinations over a period of twenty-five days :

TABLE III.

	CONTROL MILK. *Colonies estimated per c.c.*			ELECTRICALLY TREATED MILK. *Colonies estimated per c.c.*		
Date.	*Colonies on Agar.*	*Colonies on Gelatine.*	*Colonies on Neutral Red Agar*, B. coli, &c.	*Colonies on Agar.*	*Colonies on Gelatine.*	*Colonies on N. R. Agar*, B. coli, &c.
1.8.18	47,000,000	Liquefied	132,000	165	64	0
2.8.18	6,480,000,000	Liquefied	720,000,000	980	0	0
3.8.18	6,600,000	1,820,000	510,000	1,200	765	0
7.8.18	14,740,000	18,600,000	39,000	1,180	1,300	0
13.8.18	Innumerable	Innumerable	327,000,000	920	1,720	0
19.8.18	1,074,000	1,428,000	96,400	437	670	0
22.8.18	3,780,000	14,440,000	7,800	422	48	0
23.8.18	4,260,000	2,790,000	269,000	1,820	1,390	0
24.8.18	15,200,000	17,040,000	1,720,000	762	1,080	0
26.8.18	10,000,000	1,260,000	109,000	84	29	0
27.8.18	Innumerable	1,220,000	132,000	0	33	0
28.8.18	2,940,000	1,500,000	96,000	0	20	0
29.8.18	19,200,000	Liquefied	110,000	120	184	0
31.8.18	6,120,000	570,000	84,000	510	0	0
2.9.18	3,960,000	4,020,000	26,400	5	0	0
3.9.18	660,000	63,000	4,200	30	0	0
4.9.18	1,728,000	862,000	14,300	38	9	0
5.9.18	786,000	427,000	900	1,320	0	0
6.9.18	970,000	112,000	8,800	59	0	0
7.9.18	331,000,000	7,630,000	115,200	780	89	0
9.9.18	11,380,000	13,800,000	47,400	840	0	0
10.9.18	5,580,000	1,200,000	53,000	430	0	0
11.9.18	80,000	60,000	3,500	20	0	0
13.9.18	522,000	237,000	2,400	1,150	670	0
14.9.18	1,440,000	96,000	33,600	1,290	0	0

These results are sufficient to indicate that this electrical method, whatever the lethal factor may be, is a much more efficient method of ridding milk of bacteria than are processes at present in general use. The method is easy of application, the results obtained are regular, and the risks of after-contamination are comparatively small if the rules of ordinary cleanliness are attended to. The milk, especially if rapidly cooled, can be kept for several days at ordinary room temperature without any apparent change. On several occasions we have kept the milk in the laboratory for a week without any obvious change, and in a few instances it has remained perfectly sweet for a fortnight. The keeping power depends on the degree of destruction of bacteria, and, as will be seen from the table above, this varies considerably. It can, however, be said that in all cases the milk remains in perfect condition for at least two or three days.

The primary objects of these experiments were twofold, namely to investigate the possibility of using electricity as a sterilizing agent, and, if such action could be demonstrated, to devise apparatus suitable for the treatment of large volumes of milk. The experiments were carried out with the milk used for infant feeding at the Liverpool Infant Welfare Centres, and special attention was directed to the destruction of *B. tuberculosis*, *B. coli* and its allies. The process has, however, wide application in other fields of industry.

In the earlier experiments the effects of direct electric currents on milk were observed and various types of apparatus were made and used, but in no case could the results obtained be looked upon as satisfactory. Evidence of bacterial destruction was obtained, but the chemical changes in the composition of the milk were always so pronounced that the use of the direct current was abandoned.

Similarly, no satisfactory results were obtained by experiments in which differences of electrical potential were arranged, but in which the current used was negligible in quantity, i. e. static electricity.

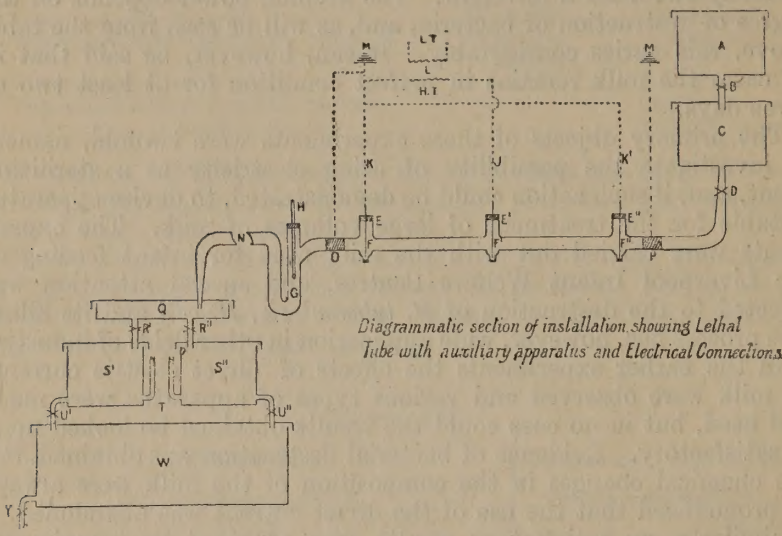
Finally, alternating currents were used and even the initial experiments gave such satisfactory results that it was decided to confine further investigation to this type of current; various forms of apparatus were employed, but these need not be referred to here, and it was finally decided that the type of apparatus shown in Diagram I, in which the milk was in constant flow, gave the most satisfactory results.

The main reasons for the adoption of this form of apparatus were:

1. That if large quantities of milk were to be dealt with economically the most likely method would be one in which the milk could be treated in 'flow', and therefore, continuously. It was felt that any 'holding' system would not be so satisfactory.
2. That, for sterilization to be effective, every portion of the milk must receive equal exposure to the influence of the electric current. We realized that the efficient treatment of every portion of the milk was an experimental necessity, for, if the slightest admixture of 'treated' with 'untreated' milk occurred, the resulting bulk sample would be contaminated, and the result of a bacteriological examination of such a

sample would be misleading when taken as evidence of efficiency. This imperative condition we felt could be most efficiently attained by exposing the milk in a cylindrical column, the area of which could be adequately commanded by the surface of an electrode.

As the efficiency of the apparatus had necessarily mainly to be gauged on bacteriological results, it was, of course, essential that accurate and carefully controlled bacteriological investigations should be continuously carried out over a fairly long period, and



Diagrammatic section of installation showing Lethal Tube with auxiliary apparatus and Electrical Connections.

DIAGRAM I.

A = covered receiving tank for untreated milk; B and D = taps; C = constant level tank; E, E′, and E″ = electrode chambers; F, F′, and F″ = electrodes; O, P = aluminium earthing tubes (the portion of the apparatus between O and P is the 'Lethal tube'); K, K′, and J = electric cables; L = transformer; LT and HT = low and high tension; M = earth connexions; H = thermometer; G = thermometer holder; N = outlet pipe from lethal tube; Q = covered channel leading through tapped pipes, R′, R″ to S′ and S″ = auxiliary tanks; T = level gauges; U′ and U″ = outlets from auxiliary tanks; W = main tank for treated milk; Y = outlet.

that all the factors concerned should be carefully noted. The general plan of each experiment was as follows:

Milk was allowed to flow continuously through the tube, and at a given time the current was applied and the following factors observed:

(*a*) The velocity of the milk flowing through the tubes.
(*b*) The terminal voltage.
(*c*) The amount of current used.
(*d*) The temperature of the milk at the outlet of the apparatus.
(*e*) The bacteriological efficiency under the conditions of the particular experiment.

The value of each of these factors, except the last one, could be altered at will, enabling numerous experiments to be made in which

one or more of the factors was varied. It was possible to obtain evidence of the most suitable value of each factor for bringing about the desired sterilization without obvious chemical alteration in the milk.

A. In which the time of exposure and the amperage are varied. The following are illustrative experiments:

TABLE IV.

Experiment.	*Time of Exposure (seconds).*	*Terminal Voltage.*	*Amperes.*	*Temperature of milk leaving Apparatus.*	*Bacteriological Results, i.e. number of* B. coli+ *per c.c.*
1	4	2,500	0·4	60° C.	Nil.
3	3	2,500	0·25	30° C.	642
4	3·5	2,500	0·4	45° C.	27

The control bulk sample used in experiments 1 and 3 showed 22,080 colonies of *B. coli* per c.c.

The milk used in experiment 3 was, after treatment, used for experiment 4.

B. In which the milk was re-treated on three occasions with a fixed time exposure voltage and amperage.

TABLE V.

Exposure.	*Terminal Voltage.*	*Amperes.*	*Temperature.*
3 seconds	2,000	0·4	50–60

Control milk showed	14,700	B. coli	*per c.c.*
After first passage	89	,,	,,
After second passage	14	,,	,,
After third passage	0	,,	,,

The milk after the first and second treatment was rapidly cooled and re-treated. Between each experiment the apparatus was cleansed with boiling water, thus ensuring a fair degree of sterility.

This experiment shows the progressive diminution in *B. coli* content of milk by the repetition of treatment under conditions detailed above.

A summary of all the experiments showed definitely that the total number of bacteria destroyed varied according to the value of the different factors concerned in the process.

DISCUSSION OF THE VARIOUS FACTORS AS APPLIED IN THIS APPARATUS.

Length of time of Exposure to Electrical Influence.

If the speed at which the milk flows, as apart from the amount of milk flowing, be varied, it follows that the length of time a unit volume of milk, or a given organism in that milk, is under the influence of the electrical current would also vary; the more rapid the flow, the less would be the length of time of exposure, and vice versa.

Assuming then that a minimum and a maximum value exist for this rate of flow—the normal value being that at which the destruction of an organism is brought about—any value above the maximum would encourage the survival of the organism. Again, a value below the minimum would bring about the death of the organism,

but this death might be due almost entirely to temperature effects, for with a much reduced rate of flow, the temperature, other things being equal, would be correspondingly higher.

It has been shown that if the speed be reduced sufficiently the milk will boil and thus yield generally sterile plates, whereas, if the speed be sufficiently increased, the temperature rise may be hardly perceptible, and no obvious sterilization result. At the same time it has been shown that there is a speed at which, under suitable conditions, sterilizing action does take place, and this at a temperature which seems to preclude the possibility of heat-energy taking any, except a minor part, in the bactericidal action. Similar temperatures can be obtained by other than electrical means, and these do not effect sterilization. Further reference will be made to this later, but it may be stated at once that in our opinion the increased temperature is not the actual sterilizing agent, but since the temperature depends so entirely upon the other factors and can be so readily observed, it forms in the general use of the apparatus a useful guide as to whether the lethal action is being maintained.

The temperature can be confined within certain narrow limits, and its easily observed variation is a sensitive indicator of the unobservable slight variations in the other factors, and in actual practice an irregular variation in temperature at once demands an alteration in one or other of the remaining factors, so as to keep the temperature nearly constant.

Terminal Voltage and Amount of Current used.

There seems little doubt that normal values exist for the electrical pressure and also for the amount of current to be used. It has been shown by Thornton [1] that the electrical 'specific resistance' is not the same for all micro-organisms, and that it is also variable in the same organism according to the medium upon which it is grown. Thus :

TABLE VI.—*Specific Resistance of Bacteria.*

	Ohms per cm. cube.	*Culture Medium.*
B. coli communis	140	Agar, rather dry.
,, from fresh sewage	82	Agar, moist.
,, ,, ,,	60	Broth.
B. typhosus	250	Agar, from broth.
,,	200	,, from agar.
,,	105	Gelatine, from broth.
,,	43	Agar.
,,	120	Boiled 1 hour, 200 ohms before.
,,	35	Autoclaved 5 hours, 200 ohms before boiling.
B. enteriditis sporogenes	200	Agar.
Sewage streptococcus	45	,,
Proteus vulgaris	86	,,
B. violaceus	340	,,
Micrococcus prodigiosus	340	,,
B. subtilis	350	,,
B. anthracis	200	,,
B. acidi lactici	200	,,
,,	80	Broth.

[1] Thornton, W.M., *Proceedings of the Royal Society*, B., vol. lxxxv, 1912.

In order to see how this variation depended upon the resistance of the media themselves, the following measurements were made by Thornton :

TABLE VII.—*Specific Resistances of Culture Media, Milk, and Water.*

	Ohms per cm. cube.	
Nutrient beef agar	60–70	
Beef gelatine, 10 per cent.	115	
Turnip gelatine	275	
4 per cent. gelatine in water	290	
Broth	70–104	No two samples from different stocks the same.
Blood serum	96	Separated by standing.
Fresh blood	200	
Fibrin	245	
Fresh milk, 1 to 2 hours after milking	233	
" " " "	240	
" " " "	252	
" " " "	252	
Fresh cream	557	
Cream with acid reaction	480	
Separated milk	210	
Milk with slight acid reaction	196	
Sour milk	180	
Sour and semi-solid	169	
Tap-water with bacteria added	1,400	
Stream water	1,300	
Town sewage	1,250	

Assuming then that a micro-organism may be destroyed as the result of being influenced by a given amount of electric current acting under certain conditions, the pressure of the current used must be sufficiently high to overcome the electrical resistance of the micro-organism. If, therefore, the voltage falls below a certain minimum, then the amount of current actually carried by the micro-organism will also be below the minimal lethal value, and death will, therefore, not take place. In other words, the voltage drop in the apparatus and the current density must be constant within defined limits. Applying this principle to the bacteria in milk it follows that merely to pass an electric current through milk will not necessarily cause the destruction of the bacteria which it contains. In fact, owing to the difference in specific resistance, any given bacterial cell may be relatively uninfluenced by it.

Again, for the destruction of the bacterial cell, both the length and the diameter of the tube in which the milk is subjected to the electric current play an important part, and these two factors will be determined in part by the amount of milk it is desired to treat. It is obvious that if in any given apparatus with a tube of a given length a certain amount of milk can pass through in a specified time, if the length of the tube is reduced by one half, then the rate of the flow of the milk would have to be reduced, if each unit volume of milk had to be under the electrical influence for the same length of time, whereas if the tube length is increased the rate of flow would also require to be increased. By variation of the tube length,

however, the other factors will be thrown out of proportion, for it would follow that the longer the column of milk the higher must be the terminal voltage. It is undesirable, however, to have undue length of tube, and, in order to avoid this, the diameter of the tube may be increased. Here again, however, great care must be exercised in order that the current density, i. e. amperes per square centimetre of milk section, be not reduced below the minimum value required for killing the bacteria.

From our general experience it is clear that under normal conditions these working factors should not vary above or below certain well-defined maxima and minima, and a successful operation, as determined by a bacterial count, is dependent on a correlation of all the factors.

Many experiments were undertaken in order to decide the nature and extent of this correlation, but it is only necessary that a few of these should be given in detail.

TABLE VIII.

Experiment.	*Terminal Voltage* *1.	*Amperes.* *2.	*Temperature in Degrees C.*	*Time in minutes for two litres to flow through apparatus.*	*Apparent Watts.*	*Watt-seconds* *3.	*Bacteriological results* *4.
a	2,300	0·42	62	6	966	8,694	Sterile
b	2,550	0·45	64·5	4	1,147	6,882	Sterile
c	2,550	0·45	64	4·5	1,147	8,029	1 colony
d	3,050	0·40	35	4	1,220	7,320	+ +
e	2,650	0·44	53	3	1,166	5,247	+ + +
f	3,000	0·41	41·5	4	1,230	7,380	—
g	1,860	0·39	68	5	725	5,687	Sterile

*1=*Terminal Voltage* is the calculated average of several observations.

*2=*Amperes* is the calculated average of several observations.

*3=*Watt-seconds* is the product of apparent watts, and time of exposure in seconds. (When two litres of milk passed through the apparatus in two minutes, the exposure to the current was 3 seconds.)

*4=The bacteriological results in this case are the number of colonies growing on neutral red agar. *B. coli* growth was that taken as an indicator in most of the experiments, for it was shown that the total count was, broadly speaking, always reduced in proportion to *B. coli* destruction, i. e. the greatest reduction in 'total numbers' occurred when *B. coli* were totally destroyed.

In the above series of experiments, *d*, *f*, and *g* may be excluded; *d* and *f*, because of the low temperature, and *g*, because of a possible error in time reading. It will be noted that in *e* the temperature reached only 53° C., and the bacteriological finding was bad.

In *a*, *b*, and *c* the temperature varied between 62° and 64·5° C.—the terminal voltage, the amperage, and the time of exposure were fairly uniform and the bacteriological finding was satisfactory.

These results suggested that further experiments should be carried out in which the terminal voltage, the amperage, the time of exposure, and the temperature should approximate those used in experiments *a*, *b*, and *c*. Some of these experiments are detailed in Table IX below.

TABLE IX.

Experiment.	*Terminal Voltage.*	*Amperes.*	*Time in minutes.*	*Temperature in degrees C.*	*Bacteriological Results, Neutral Red Bile Salt Lactose Agar.*
1	2,540	0·42	7	61·5	No growth in 36 hours,† 1 colony 48 hours' incubation.
2	2,620	0·43	7	64·5	No growth in 48 hours.
3	2,500	0·41	6·5	60·6	No growth 36 hours, 1 colony 48 hours.*
4	2,500	0·41	6·5	59·4	No growth 36 hours, 1 colony 48 hours.*

† On control plates the colonies of *B. coli* were so numerous as to be practically uncountable.

* The colony in each case was a minute red colony, which proved to be a coccus. No colonies of *B. coli* developed.

Though these results were satisfactory, it was decided to try whether by using an increased amount of current (higher amperage) the time of exposure might be lessened, for it is obvious that if the time of exposure be reduced the yield from a given 'lethal tube' would be increased, the influence of heat reduced, and the apparatus, to such an extent, improved.

The following experiment shows the result of such an increased current, with a higher rate of flow.

TABLE X.

Terminal Voltage.	*Amperes.*	*Time in Minutes.*	*Temperature.*	*Bacteriological Results.*
2,550	0·51	5	65° C.	Neutral red plates sterile. Control uncountable.

Following this successful result, other experiments, some of which are given in Table XI, were carried out with still greater amperage, increased terminal voltage, and a lessened time exposure.

TABLE XI.

Showing further Experiments with decreased Time-factor, with increased Terminal Voltage, and with increased Current.

Experiment.	*Terminal Voltage.*	*Amperes.*	*Time in Minutes.*	*Temperature*	*Bacteriological Results. Neutral red plates, 48 hours' incubation.*
1	3,000	0·59	4	64	Sterile.
2	3,450	0·54	4	64	One colony of an acid producing coccus.
3	3,400	0·55	4·5	67	Sterile
4	3,450	0·55	4·5	63	Sterile
5	2,600	0·60	4	69·6	Sterile
6	2,975	0·60	4	64·5	Sterile
7	3,000	0·60	3·5	64	Sterile
8	3,080	0·51	4	68	Sterile

These experiments, 1 to 7, were made on the same day, and separate quantities of milk were used for each. Experiment 8 was made the following day with a sample of the same milk used in experiment 2—this with the other samples having been kept overnight in the refrigerator.

Numerous other experiments on these lines were carried out, and the general conclusion was that with terminal voltages between 2,500–3,500, amperage 0·5 to 0·6, a temperature of 59°–64° C., and a time exposure of four minutes, all *B. coli* could be either destroyed, or, at any rate, so altered as to completely inhibit their growth on artificial media. In summarizing our experiments we concluded that the most favourable temperature reading was between 62° and 64° C.

This question of the possibility of inhibition rather than the destruction of the bacteria was examined carefully, and our conclusion was, that actual destruction took place.

We base this conclusion on the following facts :

(*a*) Milk adequately treated showed no *B. coli* on plating.

(*b*) When large volumes of such treated milk were incubated at 37° C. for four days and tested daily, no *B. coli* were found.

(*c*) If this milk was inoculated with *B. coli* there was no inhibition of growth.

(*d*) When inoculations were made of the treated milk on to any media on which *B. coli* ordinarily grows, no trace of this organism could be found, though other bacteria present in the milk developed quite satisfactorily.

The experiments with tuberculous milk were also successful, but it will be more convenient to deal with these at a later part of the paper.

During these experiments, certain technical difficulties arose, and, as a result, modifications in the design of the apparatus were made, but the only one that need be referred to was the introduction of the present electrode chambers. These were so constructed that the flow of milk would not be impeded, that no eddies would form, and that the whole of the milk passing through the chamber would be without doubt controlled by the electrode.

It was, of course, obvious that if the apparatus was to be of value commercially, it would be necessary to establish that it would work continuously and effectively for long periods. Tests to this end were, therefore, carried out, and it was shown that the small experimental plant worked consistently well during the whole of a nine hours' run.

At this stage of the experiments it was decided to introduce a larger plant in order to determine whether the apparatus would be of practical value in dealing with large volumes of milk. In this large plant the electrical apparatus consists of a direct current motor, coupled directly to a low tension single phase alternator of 50 to 80 cycles per second. The current from the alternator is conveyed to a high tension transformer, from which it is available for use in the ' lethal tube '. For the sake of safety the high tension transformer and its attendant instrument transformers are fixed in an asbestos-lined cupboard, the doors of which are automatically locked by the projecting doors of an upper chamber containing the sterilizing apparatus, or, as it is called, the lethal tube. Inside this upper chamber and suspended from the back is a slate panel. This is used for electrode attachments, and supports the glass sterilizing apparatus. The upper cupboard has a glass panelled double door

projecting below the ordinary level, thus preventing the doors of the lower case from being opened without previously or simultaneously opening the doors of the upper case. A protected switch is placed on each of the upper panels, each switch being in series with the alternator field, thus when any of the four doors are opened, the electric current generated in the alternator is cut off. The large-scale apparatus is, therefore, safe. No essential difference in design exists between the large-scale lethal tube and the small experimental tube. The difference is merely one of sectional area, which is directly proportional to the volume of milk to be treated in a given time. The non-essential differences are as follows :

1. *The use of two aluminium tubes continuous with the glass tubes.* Through one of these the milk passes immediately prior to treatment, and through the other immediately after treatment. These aluminium tubes are permanently ' earthed ', and thus ensure the safety of the operators who handle the milk before and after the sterilizing process.

2. *The electrodes.* These are of stout copper and have a screw-cap for surface contact, with a somewhat similar copper piece inside the electrode bracket described below.

3. *The electrode bracket.* The electrode chamber and its contained electrode is kept firmly pressed against an internal plate by means of supporting claws ; the internal plate is directly connected to the electric cable. The whole of the contact portions is encased in vulcanite, thus making an insulated electric connexion from the high tension cable to the milk. The flat surface connexion is made merely by placing the chamber and its electrode into the claws with the upper portion of the chamber inside the vulcanite hood.

An adjustment to make a more intimate connexion in case of need is secured by the screw head of the electrode (see Diagram II).

If the apparatus is to work efficiently the supply of milk should flow from a constant level. Therefore, two tanks on the inlet side are provided, one holding the main supply of milk and a second being fed from the first tank and being provided with a suitable inlet valve.

This inlet valve, of the floating ball type, automatically keeps the level of the milk constant.

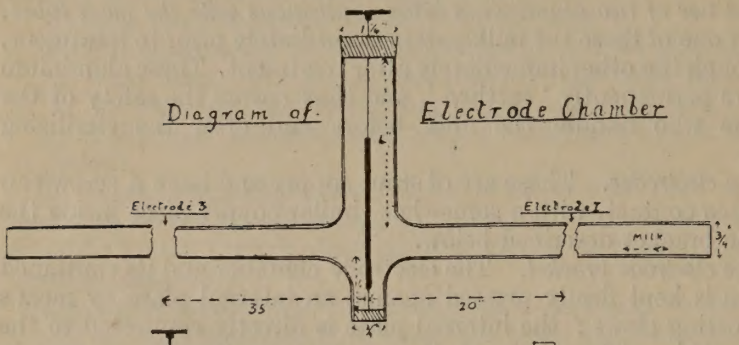
The outlet of the second, or constant level tank, is connected through a tap, with the first ' earthing ' tube, this being continuous with the ' lethal ' tube. The receiving tanks for the ' treated ' milk are ordinarily three in number, two small auxiliary tanks and a main receiving tank. The two auxiliary tanks are filled and then discharged alternately through a covered channel into the main receiving tank. By means of these two small vessels a much more efficient control of the product can be obtained, thus, in the event of any accident in the lethal tube, causing the milk to flow through untreated, or not properly treated, e.g. accidental momentary opening of a switch, then the milk flowing at the time would not contaminate the main sterilized supply, owing to its passage into the auxiliary tank. In such an event the milk in the auxiliary tank would after readjustment of the apparatus be returned to the untreated supply.

One need but mention the necessity of the receiving tanks being

thoroughly sterilized before use and protected from all contamination during use. A diagrammatic representation of the essential installation is seen in Diagram I.

After installation this larger apparatus was used for much experimental work for three months. The greater part of the milk supply for the Liverpool Corporation Infant Welfare Centres was during that period treated by this electrical method. Before the sterilization is proceeded with it is essential to establish, on the basis of the experiments detailed, the most favourable conditions

FIG. 1.



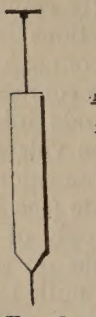


FIG. 2.

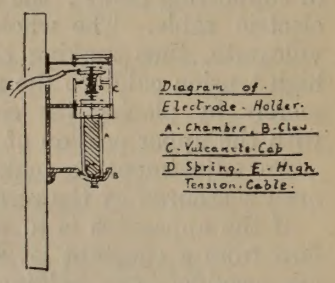


FIG. 3.

DIAGRAM II.

FIG. 1.—Diagram of representative electrode chamber with contained electrode. This is drawn to scale, and measurements are inserted.

FIG. 2.—Shows the general shape of a copper electrode.

FIG. 3.—Shows diagrammatically the arrangements for ensuring safe electrical contact.

for the treatment of the milk. Therefore, a preliminary tuning up of the apparatus is essential, i.e. the flow of milk through the lethal tube has to be so regulated that a known quantity (about 30 gallons in our apparatus) passes through it in one hour, and in this regulation of flow, variations in the factors concerned in the sterilization have to be made in order to obtain the most efficient current density and terminal temperature. When we have established these conditions, the milk is allowed to flow through the lethal tube for several minutes, before the final sterilized product is collected. Any variation of the temperature-reading, in our experience, can be controlled by very slight variations in the amount of current, and when once

this reading is steady the apparatus will do its work efficiently and with but slight attention.

The milk used during this process of ' tuning ' (which by the way takes a comparatively short time) may be returned, after it has been cooled, to the general unsterilized supply.

The following table gives an average sample of the electrical readings on any given date for the destruction of *B. coli*. (For the destruction of tubercle bacilli the terminal temperature-reading should not be below 63° C.)

TABLE XII.—84 *Gallons of Milk treated, including diluted Milk for Infants' use.*

January 27, 1914. The amperage here varies from 2·05 to 2·3, which is four times that stated on p. 13 as being necessary for the destruction of *B. coli* with the small experimental plant, as the capacity of the tube used in the larger plant is practically four times that required in the small apparatus.

Time.	*Terminal Voltage.*	*Amperes.*	*Terminal Temperature. Degrees–Centigrade.*
A.M.			
8.47	3,950	2·3	61·5
9.0	3,950	2·25	60
9.10	3,900	2·2	60·5
10.0	3,900	2·22	63
10.15	3,975	2·15	62·5
10.30	4,050	2·2	63
10.40	4,050	2·15	63
11.0	4,150	2·1	63·5
11.20	4,200	2·02	62
11.35	4,200	2·05	64
noon	3,650	2·19	62

TABLE XIII.

The following Table gives the results of the bacteriological examination, on fifteen successive days, of the milk before and after treatment:

	Control Sample (untreated milk) 1 c.c.		*Treated Milk* 1 c.c.	
Date.	*Bacteria present (grown on Agar at 37° C.).*	*Bacteria grown on Neutral Red Agar at 37° C.* (B. coli, &c.).	*Bacteria present (grown on Agar at 37° C.).*	*Bacteria grown on Neutral Red Agar at 37° C.* (B. coli, &c.).
26.1.14	777,000	1,140	642	0
27.1.14	uncountable	180	327	0
28.1.14	125,400	1,320	53	0
29.1.14	158,400	29	189	0
30.1.14	568,000	656	316	0
31.1.14	567,600	912	168	0
2.2.14	80,000	600	100	0
3.2.14	97,500	798	16	0
4.2.14	126,500	105	22	0
6.2.14	35,400	436	0	0
8.2.14	96,400	25	87	0
10.2.14	152,460	17	130	0
12.2.14	112,200	676	75	0
13.2.14	19,840	96	348	0
14.2.14	950,000	432	49	0

It will be seen from the above table that :

(*a*) The average reduction of bacteria, as indicated by agar culture during the period, was over 99·9 per cent.

(*b*) *B. coli* were always absent from the treated milk.

(*c*) Although the total reduction was always considerable, on only one occasion was the agar plate sterile.

Destruction of B. tuberculosis.

In previous publications, *Journal of State Medicine*, April 1916 and June 1916, we have given details of experiments in the sterilization of tuberculous milk, and it is therefore only necessary to summarize our results here.

Milk artificially infected with pure cultures of *B. tuberculosis* and also with sputum containing large numbers of this organism, was rendered free as tested by guinea-pig inoculation. On eight different occasions, between January and March 1914, we found in our routine examination that the control samples from the Infant Welfare centre produced definite tuberculosis in guinea-pigs, whereas, from the treated milk of the same days the guinea-pigs were not affected and no trace of *B. tuberculosis* was found on microscopical examination of the glands six weeks after the date of inoculation.

In 1916 we carried out some experiments at Birmingham, with the consent of Professor Leith, with a milk that was very rich in *B. tuberculosis*. These results were published in the *Journal of State Medicine* for June 1916. These showed that if the electrical conditions were such that the temperature at the outlet of the tube was kept constant between 62° C. and 64° C. total destruction of *B. tuberculosis* was brought about. Our previous and later work confirmed this observation, and we suggest that for the destruction of *B. tuberculosis* the outlet temperature should be 62° C. to 64° C., and particularly so if the organisms are present in considerable numbers.

Experiment illustrating the effect of electrical treatment on tuberculous milk with special reference to the terminal temperature.

The plan of the experiments was as follows :

The tuberculous milk was allowed to flow through the apparatus, the electrical current was applied, and both the flow and the current suitably adjusted. When it was judged that the lethal effect of the process was being exerted, milk flowing from the delivery end of the tube was collected in bottles—the temperature of the milk on delivery was 63° to 64°. These samples constituted Series I.

The electrical conditions were then varied so that a lower terminal temperature would be obtained and further samples (Series II, A to D) were collected.

A	when the terminal temperature was			60° C.
B	,,	,,	,,	60·7° to 62° C.
C	,,	,,	,,	60° to 61° C.
D	,,	,,	,,	62° C.

The current dimensions were then corrected to the magnitude obtaining when the samples in Series I were taken, and after the lapse of a few minutes, fresh samples (Series III) were taken with a terminal temperature of 63° to 64° C.

The voltage and amperage in this experiment was as follows:

Volts.	*Amperes.*
5,600 to 6,000	0·45 to 0·5

These voltage figures are unusually high, probably indicating abnormality in the milk which one would naturally expect in a milk from a definitely tuberculous animal, and this abnormality may have some bearing on the results of the experiment. Our former experiments were carried out with the usual milk of commerce.

The samples thus taken were dealt with as detailed below. In Series I, five 4 oz. samples were pooled, and the centrifuged deposit from 100 c.c. of this milk inoculated into each of two guinea-pigs.

In Series II, two guinea-pigs were inoculated with the centrifuged deposit from 100 c.c. of each sample (A, B, C, D). In Series III, five 4 oz. samples were treated as in Series I. Four guinea-pigs were inoculated each with the centrifuged deposit from 100 c.c. of untreated milk.

The results are recorded in the following table:

Control Experiments. (Untreated Milk.)

Guinea-pig	(1)	Killed four weeks after inoculation, marked tuberculosis of glands at site of inoculation, of lumber glands, and of spleen and liver.
	(2)	
	(3)	
	(4)	

Series I.

Temperature 63° to 64° C. Two guinea-pigs inoculated. Killed six weeks after inoculation. No trace of tuberculosis.

Series II.

A. 60° C. Guinea-pig 1.—Glands at the site of inoculation were slightly enlarged, but were definitely tuberculous. Tubercle nodules were present in the spleen.

Guinea-pig 2.—No enlarged glands were present, but some nodules in the spleen showed the presence of *B. tuberculosis.*

B. 60·7°–62° C. Both guinea-pigs corresponded with 1 A above.

C. 60°–61° C. One guinea-pig died six days after inoculation, the other showed extensive tuberculous infection.

D. 62° C. One guinea-pig died six days after inoculation, the other showed no evidence of tuberculosis.

Series III.

63°–64° C. Neither of the two guinea-pigs showed any evidence of tuberculosis. They were killed and examined six weeks after inoculation.

A natural criticism of our results is that the *B. tuberculosis* in most samples of milk is not numerous, and in the small quantity

taken for inoculation it may chance that no *B. tuberculosis* would be present. As all our inoculations were done from the centrifuged deposit of 100 c.c of milk we do not admit the validity of the criticism. At the same time, we would point out that in the Birmingham experiments recorded above the *B. tuberculosis* were in enormous numbers, and no sample of 100 c.c. could possibly be taken free from this organism. Further, in one of our experiments we took 500 c.c. of a tuberculous milk before and after electrical treatment, centrifuged each 500 c.c., and inoculated the whole of the deposit subcutaneously into a series of guinea-pigs—(five with the untreated deposit and five with the deposit from the electrically treated milk).

The animals were killed at the end of six weeks, and the five with the untreated milk showed tuberculous glandular enlargement at, and leading from, the site of inoculation. No trace of tuberculosis—naked-eye or microscopically—could be found in any of the five animals inoculated with the deposit from the treated milk.

Thus we feel we are justified in claiming that this electrical treatment is an efficient method of destroying *B. tuberculosis* in milk, provided that the electrical conditions which we have described are fully and accurately carried out.

Bacteriological Examination of Milk before and after Treatment.

Separate samples of milk before and after treatment were examined bacteriologically by Professors Delépine, Ritchie, and Sims Woodhead.

Professor Delépine's conclusions were as follows :

The most important differences between Sample A and Sample C can be summed up as follows. (A was treated milk, C untreated.)

1. *When tested by cultivation in peptone gelatine :*

Sample A appeared to be sterile.

Sample C contained a large number of bacteria of at least five dominant types. The total number of colonies growing in four days was found to be over 350,000 per c.c., of which at least 1,700 were colonies of *B. coli.*

2. *When tested by cultivation on litmus agar incubated at* 37° :

Sample A yielded approximately 800 colonies per c.c. of which none had the characters of colonies of *B. coli.*

Sample C. 1,800 colonies per c.c., of which at least half had the characters of the *B. coli.*

3. *When tested by cultivation in peptone bouillon at* 42°, *quantities of :*

Sample A below 1/100 c.c. yielded no growth.

Sample C below 1/1,000 c.c. yielded no growth.

Sample A above 1/100 c.c. the growth contained no typical *B. coli.*

Sample C above 1/100 c.c. the growth contained typical *B. coli.* (The growth obtained from 1/100 c.c. contained only cocci.)

4. There was a peculiarity to which I must attract attention. When comparing the results of cultivation on gelatine and of cultiva-

tion in bouillon, and on agar at higher temperatures, I noticed that the latter yielded growth of organisms which are capable of growing in gelatine, and which were undoubtedly present in the quantities of milk used to make the gelatine plates, and yet no growth was obtained in these gelatine plates. There seemed to be, therefore, something inhibiting their growth. In order to satisfy myself that this was the case, I melted two of the sterile plates by adding to them a large quantity of peptone bouillon and incubated the mixture at 37°. I found that the plates made with 1/10 and 1/100 c.c. contained living bacteria corresponding to those found in the tubes of bouillon to which 1/10 and 1/100 c.c. of the original milk had been added directly. These organisms were chiefly sarcinae and fairly large bacilli of the *Bacillus mesentericus* type.

Professor Ritchie gives the following results :

Sample marked A (untreated).

The lactose MacConkey plates and the lactose bouillon tubes were incubated at 37° C. for forty-eight hours and were then read, and it was further found that the gelatine plates inoculated with Sample A had also by that time developed their colonies sufficiently for enumeration to be made.

1. *Total number of bacteria growing on gelatine at room temperature.* It was found that the plates most suitable for enumeration were those prepared with the 1 in 100 dilution of the milk, and it was found that, taking the average of the two plates in round numbers and allowing by calculation for the dilution, there were 180,000 bacteria per cubic centimetre of the whole milk, the proportion of non-liquefying to liquefying organisms being about 8 to 1.

2. *Lactose agar plates.* Here the 1 in 10 plates were used for enumeration, and again taking the average of the two plates, the result was 2,600 bacteria per c.c. of the whole milk.

3. *Lactose MacConkey bouillon tubes.* Here there was the formation of acid and gas in all the tubes down to, and including, that containing 0·75 of the 1 in 1,000 dilution. This indicates the presence of about 1,300 organisms per c.c. in the original milk which were capable of forming acid and gas from lactose.

Several strains of bacteria have been isolated from the colonies on the lactose MacConkey plates and also from the lactose bouillon tubes, but these have not yet been fully worked out. So far, however, as this part of the investigation has gone, all the organisms isolated have been Gram-negative bacilli which have not liquefied gelatine.

With regard to the interpretation of these results, the figures obtained with the gelatine plates are a representation of the total number of bacteria present in the raw milk. The most important result is that obtained with the MacConkey lactose bouillon. The fact that the gas-forming organisms were Gram-negative bacilli, not liquefying gelatine, points to the conclusion that the figure 1,300 per c.c. represents the content of the milk in *B. coli* and allied species.

Sample marked C (treated). Received March 5.

1. *Gelatine plates.* There was no growth visible on any of these plates until March 11, and it was then found possible to count the

1 to 10 plates. The calculated number of bacteria present in 1 c.c. of the whole milk was found to be 20,000.

2. *Lactose agar plates.* No growth took place in these after forty-eight hours' incubation.

3. *Lactose MacConkey bouillon tubes.* No growth took place during the forty-eight hours' incubation at 37° C., but on further standing the tubes at room temperature it was found on March 11 that there was the production of acid in the tubes containing 1 c.c., 0·75 c.c., and 0·5 c.c. of the whole milk. There was, however, no gas production.

The conclusion here is that the number of bacteria present was, compared with the other sample, small, and there was no evidence of *B. coli* being present. The last result has been confirmed by cultures made from the MacConkey bouillon tubes.

Professor Woodhead reports as follows :

(A, treated milk ; C, untreated milk.)

Sample of milk marked 'A. 10.3.14 ' from Professor J. M. Beattie, the Bacteriological Department, Johnston Laboratories, University of Liverpool, received at Cambridge railway station by 4.55 p.m., March 11, 1914, and cultures made by 6 p.m. on same day :

11 c.c. of milk put into bile salts broth gave negative results.

0·1 c.c. of milk put into bile salts agar gave negative results.

The average number of organisms growing on agar at 37° C. was 185 per c.c.

Sample of milk marked ' C. 10.3.14 ' from Professor J. M. Beattie, the Bacteriological Department, Johnston Laboratories, University of Liverpool, received at Cambridge railway station by 4.55 p.m., March 11, 1914, and cultures made by 6 p.m. on same day :

With this sample, presumptive *B. coli communis* reactions were obtained in bile salts broth with 0·00001 c.c. of milk.

In bile salts agar, 1,550,000 colonies per c.c. of milk developed, and of these about 60,000 were fairly typical *B. coli communis.*

In ordinary nutrient agar about 16,000,000 colonies developed per c.c. of milk.

Effect of Process upon Milk when used as a Culture Medium.

March 13, 1914. Samples of milk A, C (each with litmus) and fresh milk from a cow at our farm, were boiled for ten minutes, and when cool inoculated with *B. coli communis.* Next day the Laboratory milk was firmly clotted and acid. Milk C was acid with a ropy clot. Milk A was little changed, becoming acid but not clotty.

March 14, 1914. Samples of milk A and C and Laboratory milk were tinctured with litmus and put into tubes and boiled for twenty minutes. A appeared quite neutral. C was faintly acid and clotted slightly after boiling. Laboratory milk gave same reaction as A. On the addition of dilute acetic acid or HCl to samples of these three milks they clotted in an equal degree.

March 16, 1914. A number of tubes of litmus milk (A, C, and Laboratory) were inoculated with equal quantities of *B. coli com-*

munis emulsion and incubated with a view of controlling results previously obtained. Milks A and C and Laboratory milk (free from all preservatives) gave results as to acidity and clotting almost identical, bearing in mind that C was more acid to start with.

At a later period, Delépine made a further examination after he had personally collected the samples at varying intervals of time. The results were confirmatory of his previous observations, he says : ' they were of the same nature, but not quite so good as on the previous occasion.' All *B. coli* were, however, destroyed. This variation in results corresponds with those obtained by us, as will be seen in Table III. Delépine refers to ' something inhibiting their growth ', and ' it is possible that there was in one, some substance not present in the other '.

The question of inhibition was one which naturally occurred to us, and though all our evidence seems to oppose this view, yet it is a possibility that some of the organisms were inhibited in this growth and not killed. This, however, is distinctly not the case with the two special organisms which we desire to get rid of—*B. coli* and *B. tuberculosis*. The evidence given proves that they are killed. Further, in regard to the substance present in the one and not in the other, chemical investigation gives no support to this view. Traces of colloidal copper from the electrodes, which are undoubtedly slightly acted upon during the process, naturally are suggested as a possibility, but absolutely no trace of copper was found by Delépine himself or by others.

From a purely scientific point of view it would be extremely interesting to prove that some agent, chemical or other, is produced during the time of electric action, and that this substance is the real sterilizing agent, but, from the practical point of view, the value of the method would not be lessened, as a substance in such small quantities as to be undetectable by exact chemical processes is not likely to be harmful to the consumer of the milk. The presence of this substance in sufficient quantity to kill or even to inhibit the bacteria is rendered very improbable when one considers that the treated milk, as shown in many experiments by ourselves or in those noted in Woodhead's report, is quite a good medium for the growth of *B. coli* and other bacteria introduced either immediately after sterilization or at a later period.

As Table III indicates, the electrical treatment of milk by this process in our hands has generally failed to give absolute sterility —in some few cases the plates made were sterile, but incubation of larger samples always showed evidence of bacterial growth, although in some cases evidence of the presence of bacteria was delayed.

In one sample recently treated, several pints of the milk were put into a sterile bottle without any special precautions as it was intended to use the milk at once, but on account of urgent duty the bottle with the milk was left in a handbag in a bedroom and forgotten. A fortnight later it was found that the milk was perfectly sweet, and plates made from it remained sterile.

The following are the types of organisms we have found in the electrically treated milk.

(*a*) Large Gram-positive cocci.

(*b*) Small Gram-positive cocci, showing a meagre dry growth on agar.

(*c*) A streptococcus—feeble growth, which rapidly died out.

(*d*) Gram-negative cocco-bacillus.

(*e*) Various types of sporing organisms.

The cocci are for the most part acid-producers, whilst the sporing organisms are, as might be expected, alkali-producers, but in spite of this latter fact, the electrically treated milk invariably shows an acid reaction when left standing for several days.

These organisms are, of course, not all present in every sample. In each case where they are found in the treated milk they probably represent the residual organisms of that type which have escaped destruction, the majority of each type having been destroyed. This appears to be strictly true concerning the acid cocci, but is perhaps less true concerning the sporing bacilli, although, again, the number of sporing organisms present, as indicated by plate culture, is often enough in the treated milk much lower than in the corresponding untreated sample. Experiments have been made to rid the milk of these residual organisms, but no real success has been obtained. These experiments have been along the line of second treatment, with and without refrigeration, &c., but after carrying out a series of experiments we came to the conclusion that, from the practical standpoint, the advantage gained, if any, was not commensurate with the increased cost of further treatment, bearing in mind that the process, to be of use, must be economically sound. As the great bulk of the undestroyed organisms were of the coccal type, a special experiment was made in order to test whether cocci were more resistant than *B. coli*; 10 c.c. of a strong staphylococcic emulsion were added to two litres of sterile milk. The milk was then treated in the usual way and cultures made. The result was that all the staphylococci were destroyed—the plates remaining sterile.

Temperature.

The relatively high temperature reached at the outlet of the apparatus necessitated an inquiry into the question of the process of temperature rise. In order to determine this the lethal tube was interrupted at several points by placing additional electrode chambers therein, each of which was fitted with a thermometer and made water-tight.

The thermometers were standardized against each other. Milk was then allowed to flow through the apparatus and the current applied. The temperature, as indicated by the various thermometers, was noted at regular intervals.

Knowing the speed of flow, that is the time during which any unit quantity of milk was under the influence of the electric current, and also the temperature of the flowing column at several points, it was easy to make a curve showing the details of the temperature rise during treatment.

The general result, as will be seen in Diagram III, is that working under electrical and other conditions, already defined as normal, the curve of temperature against time showed a gradual rise, the

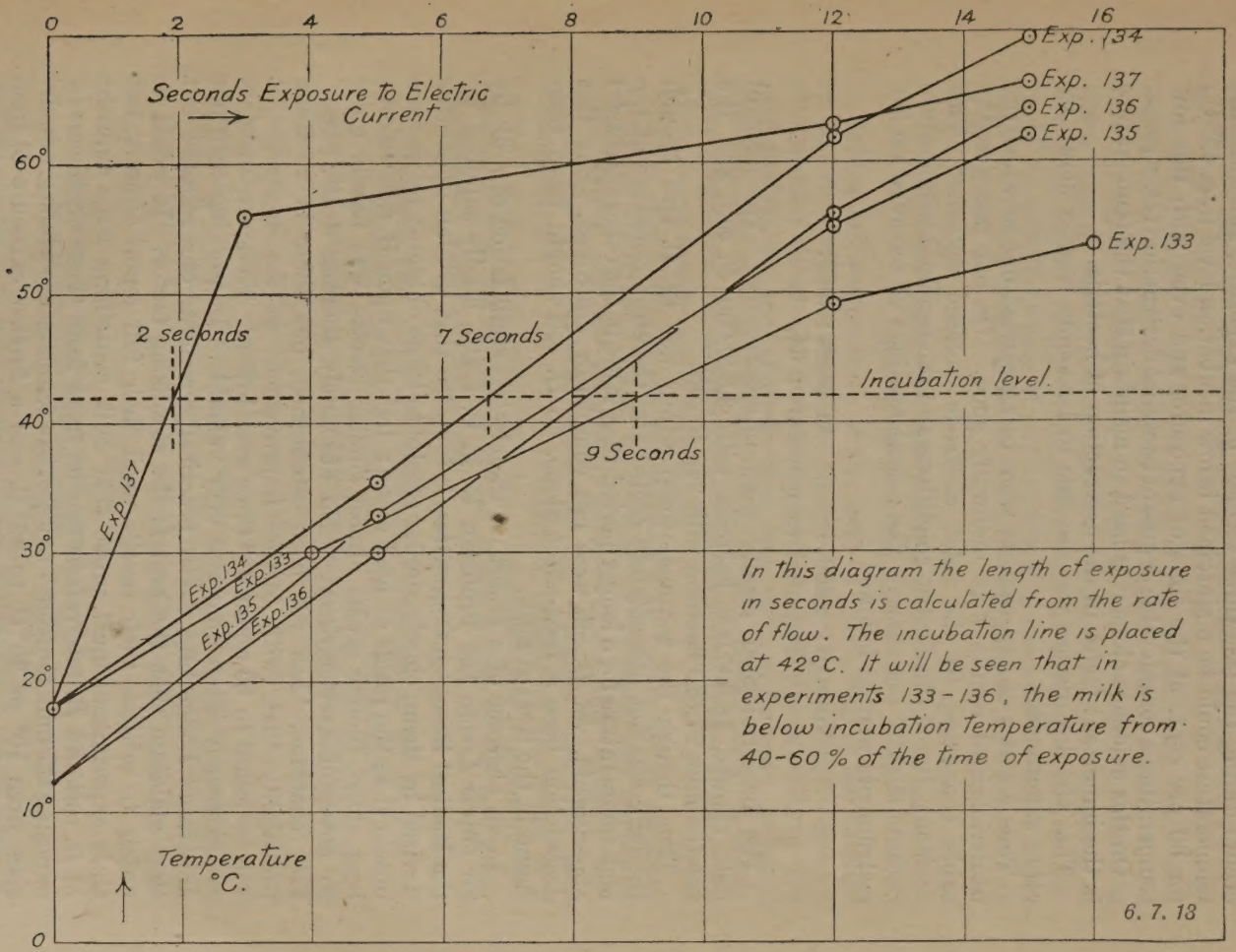

0
2
4
6
8
10
12
14
16
Seconds Exposure to Electric Current
Exp. 134
Exp. 137
Exp. 136
Exp. 135
Exp. 133
60°
50°
40°
30°
20°
10°
0
2 seconds
7 Seconds
9 Seconds
Incubation level.
Exp. 137
Exp. 134
Exp. 133
Exp. 135
Exp. 136
In this diagram the length of exposure in seconds is calculated from the rate of flow. The incubation line is placed at 42°C. It will be seen that in experiments 133 - 136, the milk is below incubation temperature from 40-60 % of the time of exposure.
Temperature °C.
6. 7. 13

DIAGRAM III.

gradient depending largely upon the position of the 'central' electrode, that the rise of the temperature from 55° C. to 64° C. occurs during the last three seconds of the exposure, and that the temperature could be maintained below incubation level (i.e. 42° C.) for 60 per cent. of the time of exposure, and even with this low temperature a considerable degree of bacterial destruction takes place.

On this evidence alone it is hard to maintain that the temperature is the important factor in the destruction of bacteria.

That the destruction was not due to heat only can be shown by other experiments.

Thus a series of experiments were being carried out in which the bacteriological results were uniformly good. On one occasion the cable connected to the inlet electrode became detached. This accident altered the electric conditions and the terminal temperature became slightly increased. The actual readings as recorded on the instruments were as follows :

Voltage : 5,400. Amperes : 0·25.
Terminal temperature : 64.

The bacteriological results were unsatisfactory. The control milk showed 18,090,000 bacteria with 3,340,000 *B. coli*, and the treated milk 27,620 bacteria with 786 *B. coli*.

Thus though the terminal temperature was 64° C. and though the milk was not immediately cooled and therefore remained at the high temperature for a longer period than it did in the other successful experiments, yet *B. coli* were not completely destroyed. Had this destruction been a heat-effect alone, no *B. coli* should have been found in the treated milk.

In an abstract of a report on the electric sterilization of milk by Sir Oliver Lodge and Professor R. F. C. Leith, kindly supplied by the Medical Research Committee, it is stated that with an apparatus devised by them, closely similar results to those obtained by us were obtained as the result of heat alone ; but that upon *B. tuberculosis*, heat alone, though giving almost similar results, was hardly quite so powerful as electricity. 'No absolutely thermal death point,' they continue, 'has yet been established, but there is a strong probability that, with further improvement in the apparatus, it will be found to be about 69° C. or even lower.' These experiments are extremely interesting and very valuable. In working with our apparatus Lodge and Leith practically confirm our results ; but they maintain that the heat is the sterilizing factor. It would be unfair to criticize their results until their full report appears, but their experiments must prove that milk containing large numbers of *B. coli* and *B. tuberculosis* can be freed from these organisms by exposing the milk for from 7 to 9 sec. to a temperature which gradually rises from 10° or 20° C. to 42° C. and a further exposure of from 3 to 5 sec. between 42 and 55° or 64° C., i. e. the exposure of milk rich in bacteria to a gradually rising temperature for a total period of 16 sec. and not more than 4 sec. of the period to a temperature above 55° C. Further it must be shown that the majority of these bacteria in milk can be destroyed, even occasionally, by an exposure of not more than 16 sec. to a temperature rising to 55° C. (Diagr. III).

(We should add that our bacteriological results were obtained from milk collected at the outlet of the lethal tube and immediately cooled so that the exposure to the maximum temperature was for a very few seconds.)

It is interesting to note that in their experiments they have been led to the conclusion that the heat factor would require to be a temperature of about 69°, whereas in our experiments, some of them done at Birmingham, with their milk and in the presence of Professor Leith, we got total destruction at a temperature of 63° to 64° C., and the whole of our experiments have led us to conclude that the optimum temperature for the destruction of *B. tuberculosis* is 63° to 64°.

Higher Temperature during Passage of Milk through Lethal Tube.

Raising the temperature of the milk to 70° C. during the passage of the current was tried, but though, naturally, a slightly greater sterilization occurred, it was decided that this temperature was inadvisable, on the grounds that the milk underwent chemical changes, that the process under these conditions did not possess any advantages over the ordinary heat sterilization, and that the wastage of electrical energy was considerable.

Again, the extra percentage-reduction in bacteria was so small as to be negligible. Thus, in a given experiment, the untreated milk showed 946,800 colonies. Treated under the ordinary conditions the number was reduced to 687 colonies. Whereas, with a temperature of 70° to 71° C. another sample of the same milk showed only a reduction to 320, i. e., the percentage purification was increased from 99·929 to 99·967, a result which would not affect the keeping qualities of the milk.

Holding the Milk at Temperatures below 60° C. for Varying Times after Electrical Treatment.

In order to effect complete sterilization, it was thought that if the milk could be kept at a temperature of 50° to 55° C. for half an hour or longer, the residual bacteria, possibly in some way made less resistant by the electrical treatment, might be destroyed. No experiments at a higher temperature than 55° C. were undertaken, for this would lead us at once into the field of Pasteurization by heat.

The following table gives one of the few experiments we carried out :

Table A.

Milk immediately after treatment contained	492	bacteria	per c.c.
Same milk kept at 55° C. for 40 minutes	587	„	„
„ „ „ 60 „	342	„	„

The results were such that we did not consider it worth while to continue work on these lines.

Cooling of the Milk after Treatment.

In order to determine the effect of cooling the milk after treatment, a sample of the electrically treated milk was immediately distributed

in 10 c.c. quantities into a series of sterile tubes. Plates were made at once from these tubes and the tubes were kept at certain temperatures, given in the following table, for three hours, and then were plated again:

	No. I. *Milk Frozen Solid in Mixture of Ice and Salt.* *Temp. of Milk 0° to −1° C.*		*No. II.* *Milk Cooled in Beaker of Water and Ice.* *Temp. of Milk =3° C.*		*No. III.* *Milk Cooled in Running Water.* *Temp. of Milk =16° C.*		*No. IV.* *Milk kept at Room Temperature.* *Temp. of Milk =27° C.*	
	Colonies per c.c.		*Colonies per c.c.*		*Colonies per c.c.*		*Colonies per c.c.*	
	Agar.	*Gelatine.*	*Agar.*	*Gelatine.*	*Agar.*	*Gelatine.*	*Agar.*	*Gelatine.*
Immediate plating	102	2,040	98	840	28	246	37	1,740
After 3 hrs. interval	86	3,120	107	4,340	3	2,220	6	2,820

NOTE: The gelatine plates were counted on the sixth day.

Later, in order to determine whether water cooling or air cooling of the treated milk in bulk materially influenced its keeping qualities, we took several two-litre flasks of electrically treated milk and divided them into two series, A and B. Series A were kept at room temperature and Series B were kept in running water until the temperature remained constant, and then similarly to Series A were kept at room temperature.

A separate flask was used each day for observation. In both cases the milk was perfectly sweet on the fourth day. On the fifth day the flavour was slightly altered, but the milk was not sour in either case.

Diagram IV shows that in the air-cooled milk the temperature is at or about the favourable growth level (40° C. to 25° C.) for a longer period than in the water-cooled.

A larger quantity, though still a relatively small volume, cooled at room temperature, may be above incubation temperature for 1½ hours, as seen in Diagram VI. Further, the temperature in air-cooled milk, even in small quantities, may vary from slightly above the incubation point (i. e. 42° C. to 25° C.), or a period of 4 hours or more according to the condition of the external temperature, &c. (Diagram VI).

It will be noted that the fall in temperature between 20° C. and 15° C. is more gradual than between 32° and 20°. In Diagram IV the fall between 3.10 p.m. and 4.10 p.m. represents 12°, whereas between 4.10 p.m. and 5.10 p.m. it is only 3°. Now the greater the bulk of the milk the more gradual will be the fall between the most suitable growth period, 42° to 25° C., and bacterial increase will be encouraged (Diagram VI).

This diagram shows an increase in the number of bacterial colonies from 140 to 5,760 in bulk-cooled (i. e. 2 litres) samples between 52° C. and 26° C., whereas, in 20 c.c. samples, where there is a rapid initial fall to 25° C., and then a more gradual one to 18° C., the colonies increase from 8 to 50.

It is, therefore, obvious that though the cooling of the milk rapidly does not destroy the bacteria, yet it is advisable that it should be done in order to get rid of the 'favourable temperature period' and prevent the rapid multiplication of any 'residual'

bacteria. The 'keeping quality' of the milk will be thereby improved. Refrigerating plant is, therefore, in our opinion, a necessary adjunct to the electrical apparatus in large-scale practice.

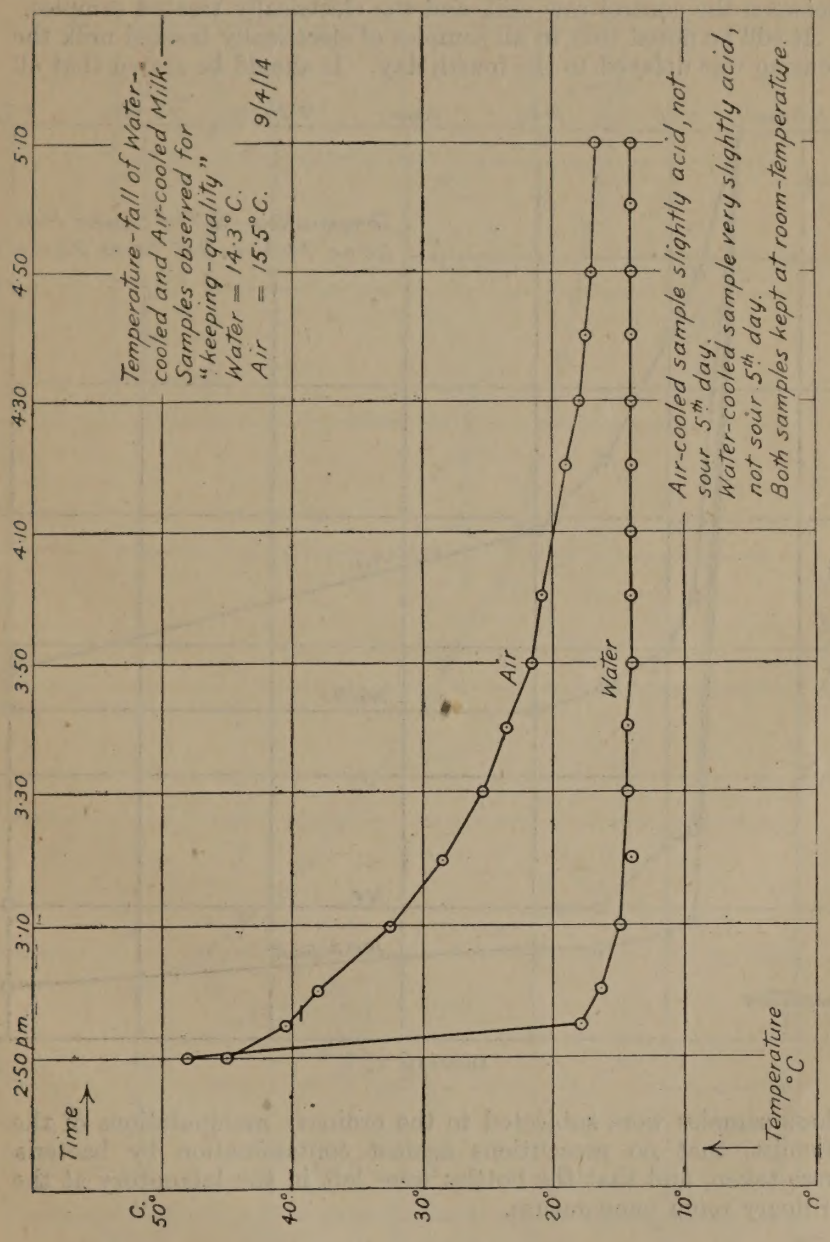


DIAGRAM IV.

CHEMICAL CHANGES PRODUCED IN THE MILK.

No obvious chemical changes were produced in the milk as the result of electrical treatment. It reacts to the usual tests for the presence of enzymes as quickly and as definitely as the control raw

milk. No trace of any copper or other metal could be found. As will be seen from Tables XIV and XV, practically no alterations in fat, albuminoids, milk sugar, mineral matter, or acidity were found between the control raw milk and the electrically treated samples.

It will be noted that in all samples of electrically treated milk the souring was delayed to the fourth day. It should be stated that all

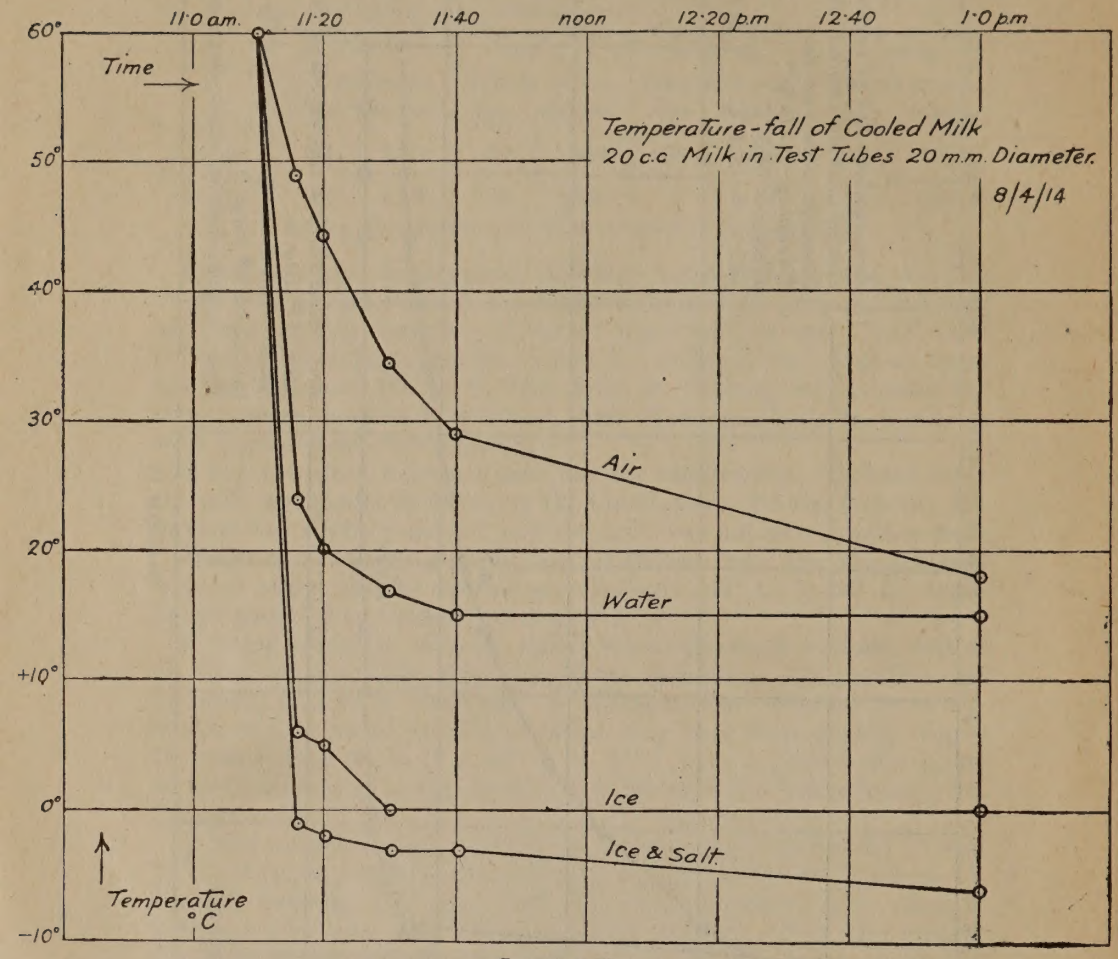


Diagram V.

these samples were subjected to the ordinary manipulations of the chemist, that no precautions against contamination by bacteria were taken, and that the bottles were left in the laboratory at the ordinary room temperature.

Feeding Experiments.

Young kittens were fed on electrically treated milk for several weeks. The controls fed on raw milk all died, whilst those fed on the treated milk increased regularly in weight. We realize that such experiments, to be of any value, must be carried out over a very

long period, and circumstances prevented us continuing this work. For several months babies were fed on this milk, and, so far as we can ascertain, did extremely well. Two of these were under close

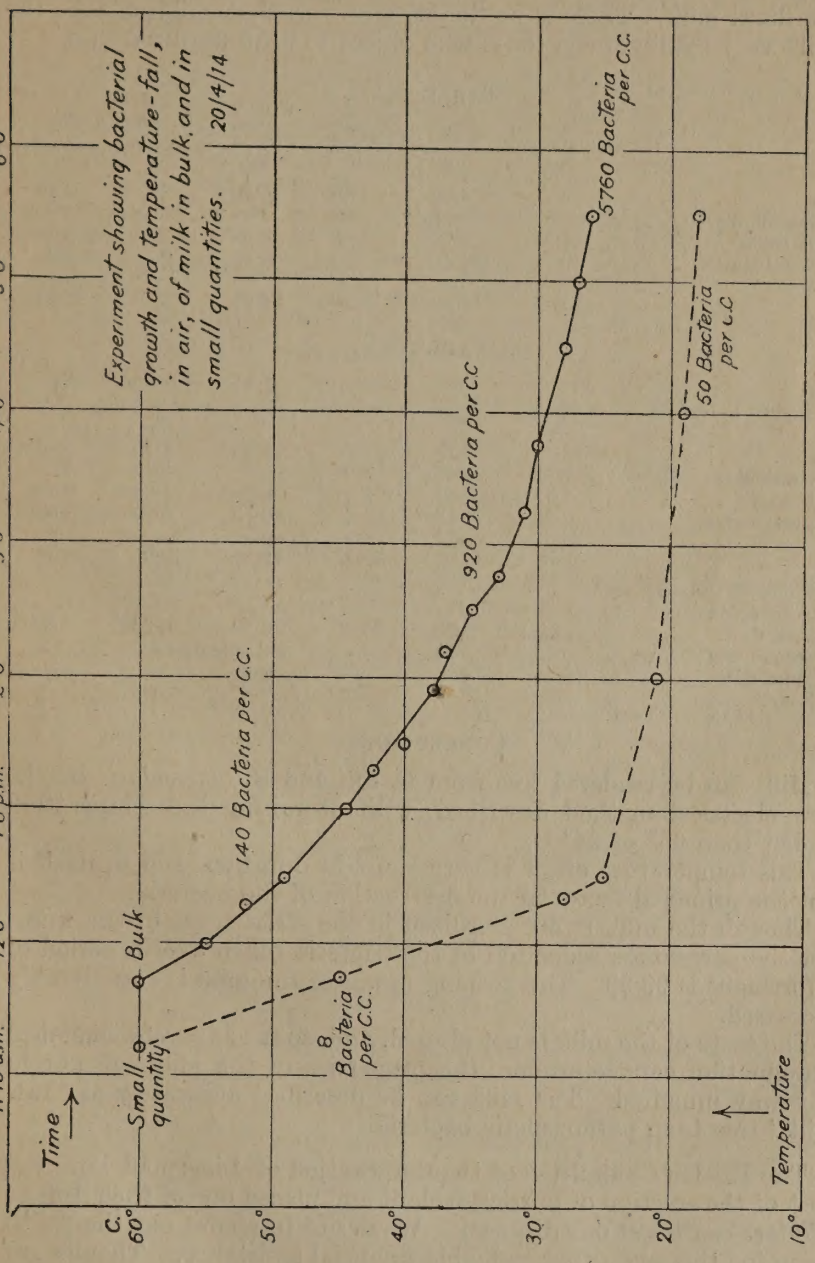


DIAGRAM VI.

observation the whole time, but with the great majority of the cases the observations were very erratic, and no conclusions of any value could be drawn from them. The two kept under close observation were the children of medical men, and it can merely be said

that both parents expressed their greatest satisfaction with the milk as a food. But we fully agree that the whole of the evidence on the food value is too feeble to enable us to draw conclusions. Possibly quite as good results would have been obtained by ordinarily heat-sterilized milk. There is no doubt, however, that children take the milk very readily, even those who object to heat-sterilized milk.

TABLE XIV.

	Treated. *No.* 1. %	*Raw.* *No.* 2. %	*Treated.* *No.* 3. %	*Raw.* *No.* 4. %	*Treated.* *No.* 5. %	*Raw.* *No.* 6. %
Fat	4·10	4·00	3·75	4·10	3·30	4·00
Albuminoids	2·81	2·81	2·88	2·86	2·88	2·88
Milk sugar	4·84	4·78	4·82	4·82	5·17	4·81
Mineral matter	0·71	0·71	0·70	0·72	0·75	0·71
	12·45	12·30	12·15	12·50	12·10	12·40

TABLE XV.

April 19 *and* 23.	*Treated.* *No.* 1. %	*Raw.* *No.* 2. %	*Treated.* *No.* 3. %	*Raw.* *No.* 4. %	*Treated.* *No.* 5. %	*Raw.* *No.* 6. %
Fat	3·35	3·35	3·30	3·30	4·20	3·65
Albuminoids	2·81	2·75	3·00	3·00	3·12	3·12
Milk sugar	5·15	5·23	5·28	5·30	4·94	5·28
Mineral matter	0·73	0·74	0·77	0·75	0·79	0·80
	12·04	12·07	12·35	12·35	13·05	12·85
Acidity calculated as lactic acid:						
First day	0·14	0·15	0·18	0·19	0·22	0·22
Second day	0·15	0·24		not calculated.		
Third day	0·35	sour	—	sour	—	sour
Fourth day	sour	—	sour	—	sour	—

CONCLUSIONS.

Milk can be rendered free from *B. coli* and *B. tuberculosis* by the new electrical method described, without raising the temperature higher than 63° or 64° C.

This temperature effect is very short in duration, and in itself is not the principal factor in the destruction of the bacteria.

Though the milk is not sterilized in the strict sense of the word, yet the percentage reduction of the bacteria taken over a period of a fortnight is 99·93. The keeping power of the milk is considerably increased.

The taste of the milk is not altered, and, so far as careful chemical examination can determine, the properties of the milk are not in any way impaired. The milk can be described accurately as ' raw milk ' free from pathogenetic bacteria.

The Health Committee of the Corporation of Liverpool bore the cost of the erection of our large plant and placed one of their Infant Welfare centres at our disposal. We desire to record our thanks to them for this and other valuable financial assistance. Thanks are also due to the Medical Research Committee for aid in carrying on the work.

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